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HEADQUARTERS
OGDEN AIR LOGISTICS CENTER
UNITED STATES AIR FORCE
HILL AIR FORCE BASE, UTAH 84056

MM2 LRSLA TESTING

STAGE III PROPELLANT

PROPELLANT LAB SECTION

MANPA REPORT
NR 480(83)

APRIL 1983

83 06 06 107

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STAGE III PROPELLANT

Author

Elizabeth M. Dalaba

ELIZABETH M. DALABA, Chemist
Component & Combustion Test Unit

Engineering & Statistical Review By

John K Scambia

JOHN K. SCAMBIA, Project Engineer
Engineering & Reliability Branch

Dan L. Petersen

DAN L. PETERSEN, Mathematician
Data Analysis Unit

Recommended Approval By

L. A. Brown

LEONIDAS A. BROWN, Chief
Component & Combustion Test Unit

Approved By

Anthony J. Inverso

ANTHONY J. INVERSO, Chief
Propellant Analysis Laboratory

April 1983

Directorate of Maintenance
Ogden Air Logistics Center
United States Air Force
Hill Air Force Base, Utah 84056

ABSTRACT

Data in this report represent the first LRSLA testing of five dissected motors. Data are compared to Grain 70 propellant which was used in first comparison testing of LRSLA methods and equipment. Problems occurred in testing C-7 bonds which resulted in poor data. Different specimen holders will be designed to alleviate these problems.

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SECTION I

INTRODUCTION

In 1968 OOALC began testing dissected motors. Changes to the program reduced the number of tests required to five per year. In 1976, humidity conditioning at 50 ± 5 percent relative humidity for 48 hours was introduced into the program. Longer conditioning times, depending upon the thickness of the test specimens began in 1981.

The data for motors tested in the current period were compared to previously tested Grain 70 data. This is the oldest CYH third stage propellant in the OOALC inventory having been cast in June 1960.

Motor serial numbers, lot numbers, cast dates and plot symbols are shown below.

Motor S/N	Lot Number	Cast Date	Symbol
Grain 70	SR-47-60	Jun 60	◇
0031064	SR-56-62	21 Oct 62	▢
0031134	SR-65-62	2 Feb 63	○
0032434	RAD-1-1-63	21 Jan 64	△
0032831	RAD-1-1-65	29 Jan 65	+
0033174	RAD-1-10-66	20 Jan 67	✕

For statistical analysis, each regression plot in this report uses the linear model $Y = a + bX$. Each point on a regression plot represents a data mean at its particular age at test. A different plot symbol is given for each motor tested. Variance about each regression line was used to compute a tolerance interval such that at 90% confidence 90% of the sample distribution will fall within this interval. This tolerance interval is extrapolated 24 months beyond the age of the last test date. The 't' value and the significance of this statistic, which are reported for each regression model, give an indication of the statistical significance of the slope of the trend line as compared to a line of zero slope.

Analysis of covariance results indicate that for any particular test, the data from each motor tested should not be combined into one overall regression analysis due to differences in variance, slopes, and trendline elevations between each set of motor data. The regression plots in this report should be used only to show visual differences between motors by means of their plot symbols.

Tables in this report show significance of differences in means by using a standard t-test. Where variances were significantly different between two sets of data, a modified t-test was used to determine the significance of difference between means.

SECTION II

STRESS RELAXATION MODULUS

Standard 0.5" x 0.5" x 4" specimens were used for this test.

Grain 70 stress relaxation data at two percent strain in the 1978
specimen evaluation program, MANCP Report 412(79), were used to compare
with motor data derived from testing in 1982. Table 2-1 has the results
of these comparisons. It can be seen that, in general, the differences
in means of the motor data from Grain 70 data are significant. A visual
representation of Grain 70 data and the data from dissected motors at
three percent strain are illustrated in Figures 2.1 through 2.3 as
linear regressions.

Table 2.2 shows two percent strain data from testing at 30°F and
300 psi. Again motor data are compared against Grain 70 data. Data
from motor 003134 has a significantly different variance from that of
Grain 70 data.

The data means of motor 0032434 and 0032831 from Radford grain are
significantly higher than the means of Grain 70.
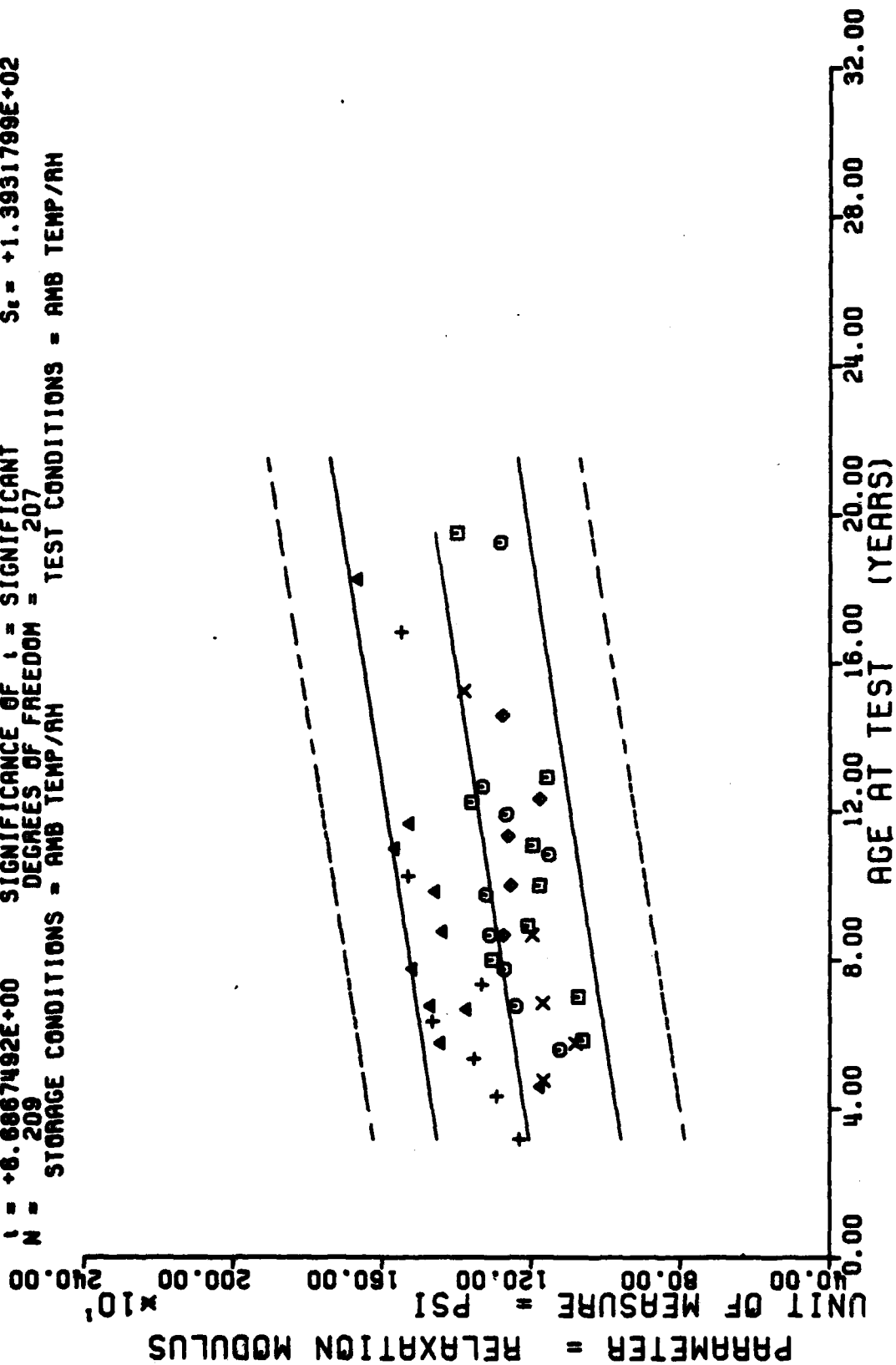
STRESS RELAXATION MODULUS AT 10 SEC AND 3% STRAIN, SIX MOTOR VISUAL DISPLAY

Figure 2-1

$$Y = ((+8.4353911E+02) + (+8.5399116E-01) \times X)$$

F = +4.0995847E+01   SIGNIFICANCE OF F = SIGNIFICANT σ_1 = +1.0613976E+02
R = +4.0658160E-01   SIGNIFICANCE OF R = SIGNIFICANT S_a = +1.3337776E-01
t = +6.4027999E+00   SIGNIFICANCE OF t = SIGNIFICANT S_c = +9.7204770E+01
N = 209   DEGREES OF FREEDOM = 207

STORAGE CONDITIONS = AMB TEMP/RH   TEST CONDITIONS = AMB TEMP/RH

AGE AT TEST (YEARS)

PARAMETER = RELAXATION MODULUS
UNIT OF MEASURE = PSI $\times 10^1$

STRESS RELAXATION MODULUS AT 100 SEC AND 3% STRAIN, SIX MOTOR VISUAL DISPLAY

Figure 2-2

$$Y = ((+6.8055475E+02) + (+6.1871406E-01) \times X)$$

F = +3.3680543E+01   SIGNIFICANCE OF F = SIGNIFICANT σ_τ = +8.3578275E+01
R = +3.7408392E-01   SIGNIFICANCE OF R = SIGNIFICANT S_a = +1.0661061E-01
t = +5.8034940E+00   SIGNIFICANCE OF t = SIGNIFICANT S_ϵ = +7.7697059E+01
N = 209   DEGREES OF FREEDOM = 207
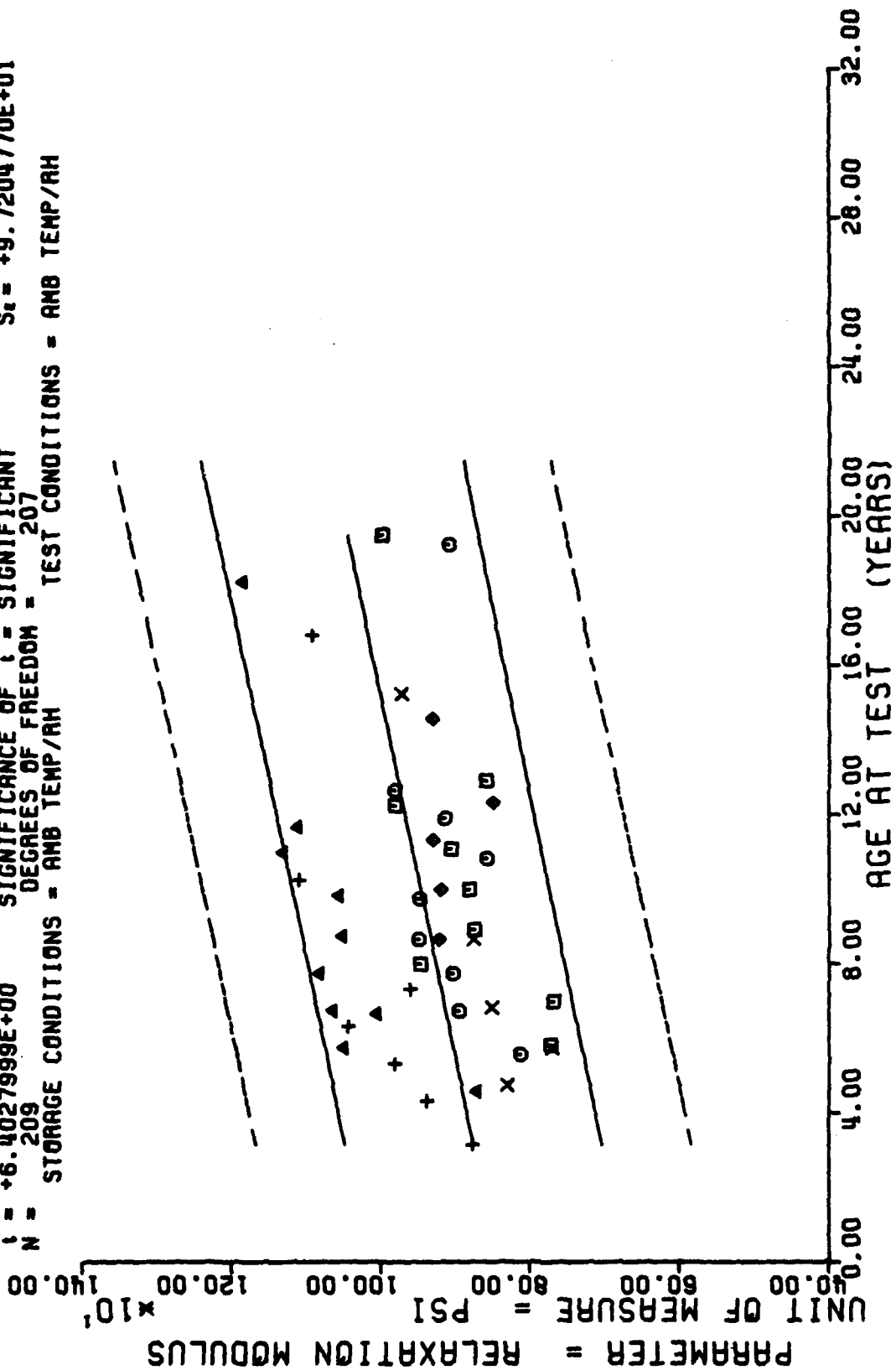STORAGE CONDITIONS = AMB TEMP/RH   TEST CONDITIONS = AMB TEMP/RH
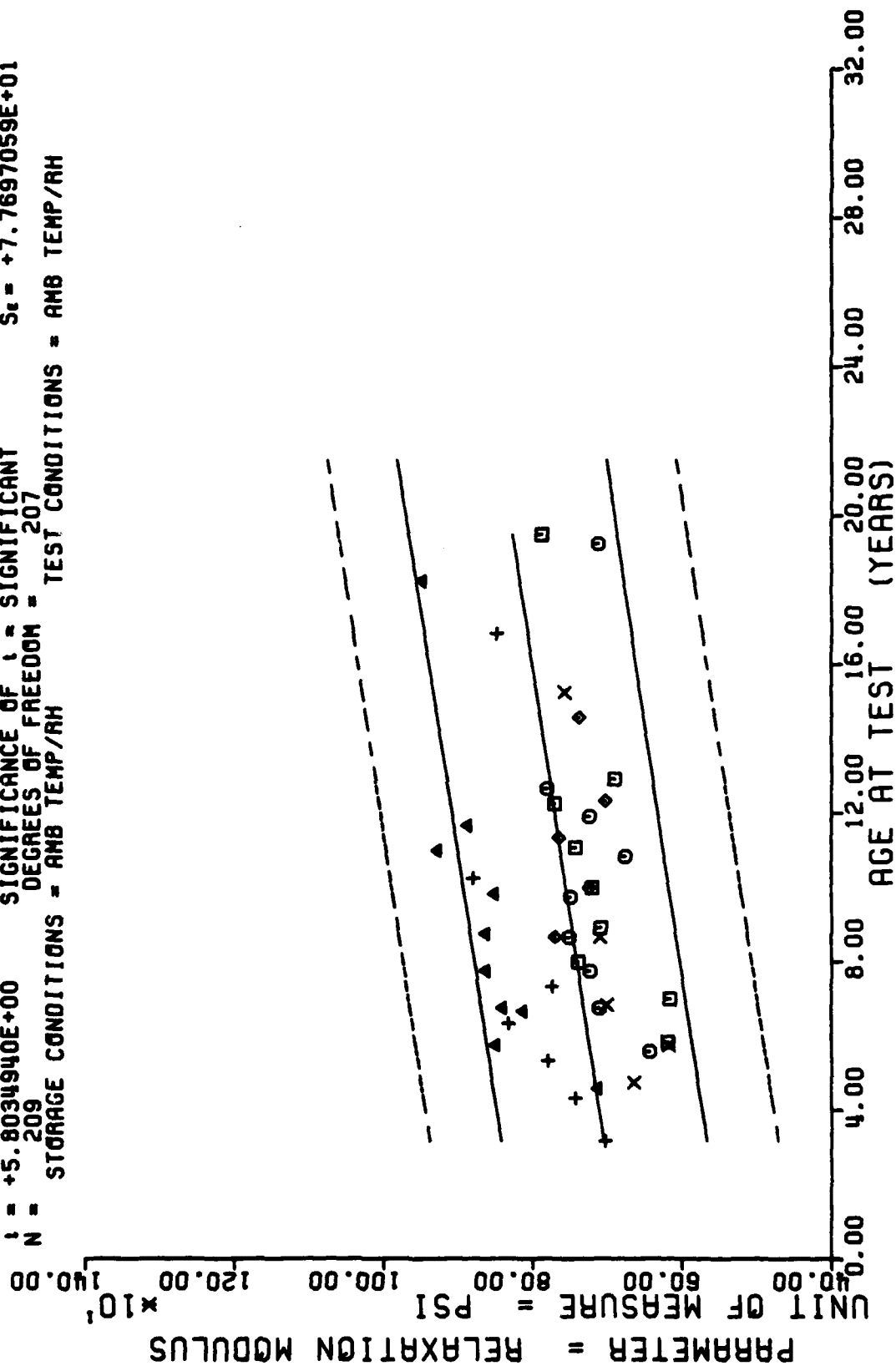
STRESS RELAXATION MODULUS AT 1000 SEC AND 3% STRAIN, SIX MOTOR VISUAL DISPLAY

Figure 2-3

PARAMETER = RELAXATION MODULUS
UNIT OF MEASURE = PSI

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TABLE 2-1

STRESS RELAXATION
2%, 77°F, No Pressure
Analysis of Difference in Means

Motor Nr	N	Parameter	Mean	Std Dev	"t"	Sig of "t"	F	Sig of F
Grain 70	10	ER_{10}	1556.1	75.79				
		ER_{100}	1158.5	45.085	Control Data from Report 412(79)			
		ER_{1000}	933.2	33.219				

Experimental Data

Motor Nr	N	Parameter	Mean	Std Dev	"t"	Sig of "t"	F	Sig of F
0031064	6	ER10	1556.7	54.94	.0168	NS	1.9030	NS
		ER100	1129.8	36.24	1.2311	NS	1.5477	NS
		ER1000	879.8	26.51	3.3555	S	1.5701	NS
0031334	5	ER10	1424.0	19.60	3.7689	S	14.9524	S
		ER100	1046.4	10.90	5.3862	S	17.1090	S
		ER1000	847.6	8.96	5.5650	S	13.7453	S
0032434	5	ER10	1777.2	79.98	5.2354	S	1.1136	NS
		ER100	1294.2	54.34	5.1483	S	1.4526	NS
		ER1000	1033.2	46.28	4.8399	S	1.9409	NS
0032831	5	ER10	1693.4	86.78	3.1597	S	1.3110	NS
		ER100	1236.6	64.08	2.7591	S	2.0200	NS
		ER1000	981.2	42.50	2.4123	S	1.6368	NS
0033174	5	ER10	1525.8	25.70	.8556	NS	8.6967	S
		ER100	1119.2	16.18	1.8601	S	7.7646	S
		ER1000	892.0	14.19	2.6173	S	5.4803	NS

NOTE: Significance of the "t" value determines whether a significant difference exists between means.

TABLE 2-2

STRESS RELAXATION
2%, 30°F, 300 psi
Analysis of Difference in Means

Motor Nr	N	Parameter	Mean	Std Dev	"t"	Sig of "t"	F	Sig of F
Grain 70	10	ER10	3930.2	731.9096				
		ER100	2229.8	369.676	Control Data from Report 412(79)			
		ER1000	1519.6	200.0879				

Experimental Data

Motor Nr	N	Parameter	Mean	Std Dev	"t"	Sig of "t"	F	Sig of F
0031064	5	ER10	4656	446.50	2.0156	NS	2.6870	NS
		ER100	2611	244.80	2.0699	NS	2.2804	NS
		ER1000	1652	169.70	1.2639	NS	1.3902	NS
0031134	5	ER10	4115	278.39	.5370	NS	6.9120	S
		ER100	2301	93.50	.4167	NS	15.6321	S
		ER1000	1370	31.42	1.6316	NS	4055.35	S
0032434	5	ER10	5350	325.15	4.0813	S	5.0669	NS
		ER100	3081	160.44	4.8533	S	5.3090	NS
		ER1000	1954	128.62	4.3786	S	2.4201	NS
0032831	5	ER10	4742	305.99	2.3444	S	57.213	NS
		ER100	2723	275.33	2.6220	S	1.8027	NS
		ER1000	1558.75	219.44	.3465	NS	1.2027	NS
0033174	5	ER10	4093	370.97	.4623	NS	3.8925	NS
		ER100	2248	272.50	.0969	NS	1.8403	NS
		ER1000	1368	311.26	1.1539	NS	2.4198	NS

SECTION III

STRAIN DILATATION

Strain dilatation tests were run on 0.5" x 0.5" x 4" specimens which were conditioned at 50 ± 5% RH for 14 days. Specimens at ambient conditions were run on a RCK Dilatometer. Pressurized specimens were tested in a dilatometer designed at OOALC for use on the MTS Tensile Tester.

Data for ambient runs were taken at pre-set strains by computer. Data for the pressurized runs were calculated based on signal readout at multiple points. These data were analyzed by regression analysis and Poisson's Ratio at strains from 10% to 30% were calculated at specified points. These data were pooled to determine the mean and standard deviation for each motor. Since dilatation did not change appreciably until at approximately 25% strain, the data at lower strains are calculated rather than real.

Grain 70 is the oldest propellant in the OOALC inventory. It was tested in 1978 and those data have been used as the reference. The significance of both means and variance are shown in Table 3-1.

For comparison, data from ambient tests are shown in Table 3-2. Tests for Poisson's Ratio were not part of the dissected motor program, and trend data are not available.

TABLE 3-1

POISSON's RATIO
200 in/min, 300 psi

Motor Nr	% Strain	N	Mean	Std Dev	"t"	Sig of "t"	F	Sig of F
Grain 70	10	10	.465	.0022				
(1978 test)	15	10	.448	.0028	Control Data from Report 412(79)			
	20	10	.427	.0033				
vs	25	9	.400	.0037				
	30	4	.375	.0019				
			Experimental Data					
0031064	10	5	.4701	.00074	4.9634	Sig	8.8385	Sig
	15	5	.4508	.00164	2.043	NS	2.9149	NS
	20	5	.4326	.00134	3.594	Sig	6.0648	Sig
	25	5	.4126	.00371	6.099	Sig	1.0054	NS
	30	5	.4105	.00116	34.7738	Sig	2.6828	NS
0031134	10	5	.4662	.00259	.9415	NS	1.3859	NS
	15	5	.4506	.00152	1.9159	NS	3.3933	NS
	20	5	.4340	.00122	4.5193	Sig	7.3165	Sig
	25	5	.4188	.00084	11.0158	Sig	19.4019	Sig
	30	5	.4028	.00192	21.6810	Sig	1.0211	NS
0032434	10	5	.4706	.00089	5.3928	Sig	6.1103	Sig
	15	5	.4508	.00109	2.1258	Sig	6.5987	Sig
	20	5	.4292	.00524	1.0045	NS	2.5213	NS
	25	5	.4094	.00546	3.8597	Sig	2.1776	NS
	30	5	.3910	.00570	5.3183	Sig	9.0000	NS
0032831	10	5	.4684	.00114	3.2052	Sig	3.7242	NS
	15	5	.4496	.00288	1.0340	NS	1.0579	NS
	20	5	.4296	.00483	1.2373	NS	2.1422	NS
	25	5	.4104	.00643	3.8956	Sig	3.0200	NS
	30	5	.3918	.00870	3.7417	Sig	2.9834	NS
0033174	10	5	.4780	.01507	2.7735	NS	46.9225	Sig
	15	5	.4506	.00055	2.0202	NS	25.9173	Sig
	20	5	.4344	.00055	4.8903	Sig	36.000	Sig
	25	5	.4182	.00084	10.6642	Sig	19.4019	Sig
	30	5	.4018	.00110	26.7027	Sig	2.9834	NS

TABLE 3-2

POISSON'S RATIO
77°F, amb Pressure

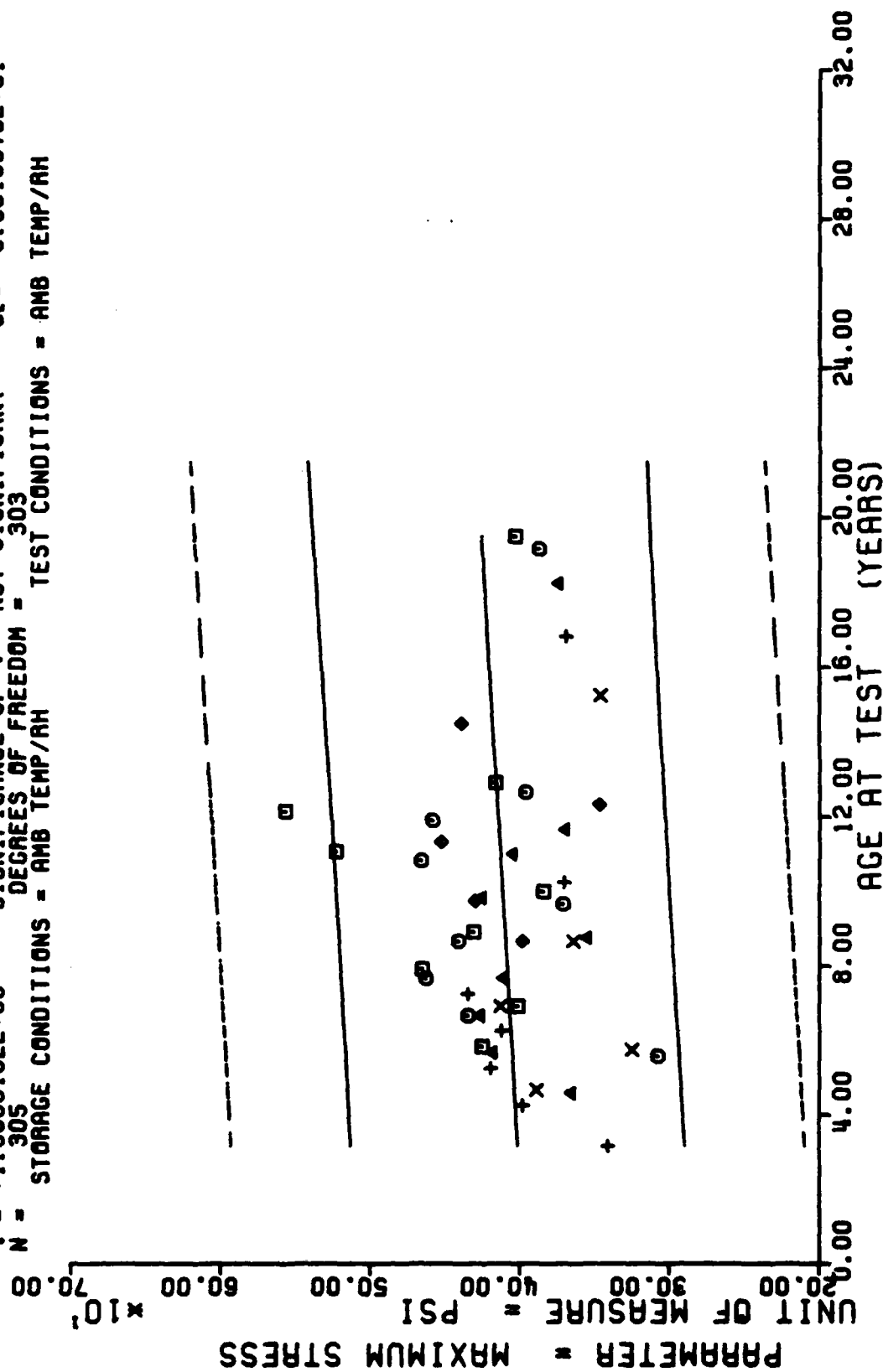| Motor S/N	N	% Strain	$\bar{X}$	S
0031064	5	10	.470	.000707
	5	15	.508	.001643
	5	20	.4326	.001342
	5	25	.4128	.003962
	5	30	.3936	.00498
0031134	5	10	.4660	.002345
	5	15	.4504	.001341
	5	20	.4346	.000548
	5	25	.4188	.000837
	5	30	.4028	.001924
0032434	5	10	.4708	.001095
	5	15	.4508	.001095
	5	20	.4292	.00526
	5	25	.4108	.00580
	5	30	.391	.00570
0032831	5	10	.4686	.001140
	5	15	.4496	.002881
	5	20	.4296	.004827
	5	25	.4108	.006834
	5	30	.3916	.008961
0033174	5	10	.4782	.001535
	5	15	.4506	.000548
	5	20	.4348	.000447
	5	25	.4182	.000837
	5	30	.4020	.001225

SECTION IV

TENSILE TESTING

Biaxial rails tested at 200 in/min and 300 psi are a LRSLA requirement. First time testing at OOALC under these conditions was done on Grain 70. The data base used for comparison purposes in Table 4-1 is for a specimen 3/16" x 2 7/8" x 5" rather than the 3/16" x 2 7/8" x 7" specimen used by Hercules. As shown in the table, means are significantly different.

Low rate biaxial are shown in Table 4-2. These data, in most cases, have significantly different means when compared to the means from Grain 70 data from the same configuration.

Each motor should be regressed separately to determine whether or not there is a significant trend in the motor data.

$$Y = ((+3.9649878E+02) + (+1.2201222E-01) \times X)$$

F = +2.4964324E+00   SIGNIFICANCE OF F = NOT SIGNIFICANT σ_r = +6.3970240E+01
R = +9.0397587E-02   SIGNIFICANCE OF R = NOT SIGNIFICANT S_b = +7.7224427E-02
t = +1.5800102E+00   SIGNIFICANCE OF t = NOT SIGNIFICANT S_c = +8.3813373E+01
N = 305   DEGREES OF FREEDOM = 303

STORAGE CONDITIONS = AMB TEMP/RH   TEST CONDITIONS = AMB TEMP/RH

AGE AT TEST (YEARS)

UNIT OF MEASURE = PSI

PARAMETER = MAXIMUM STRESS

UNIAXIAL TENSILE, MAXIMUM STRESS, 2 IN/MIN, SIX MOTOR VISUAL DISPLAY

Figure 4-1

UNIAXIAL TENSILE, STRAIN AT MAX STRESS, 2 IN/MIN, SIX MOTOR VISUAL DISPLAY
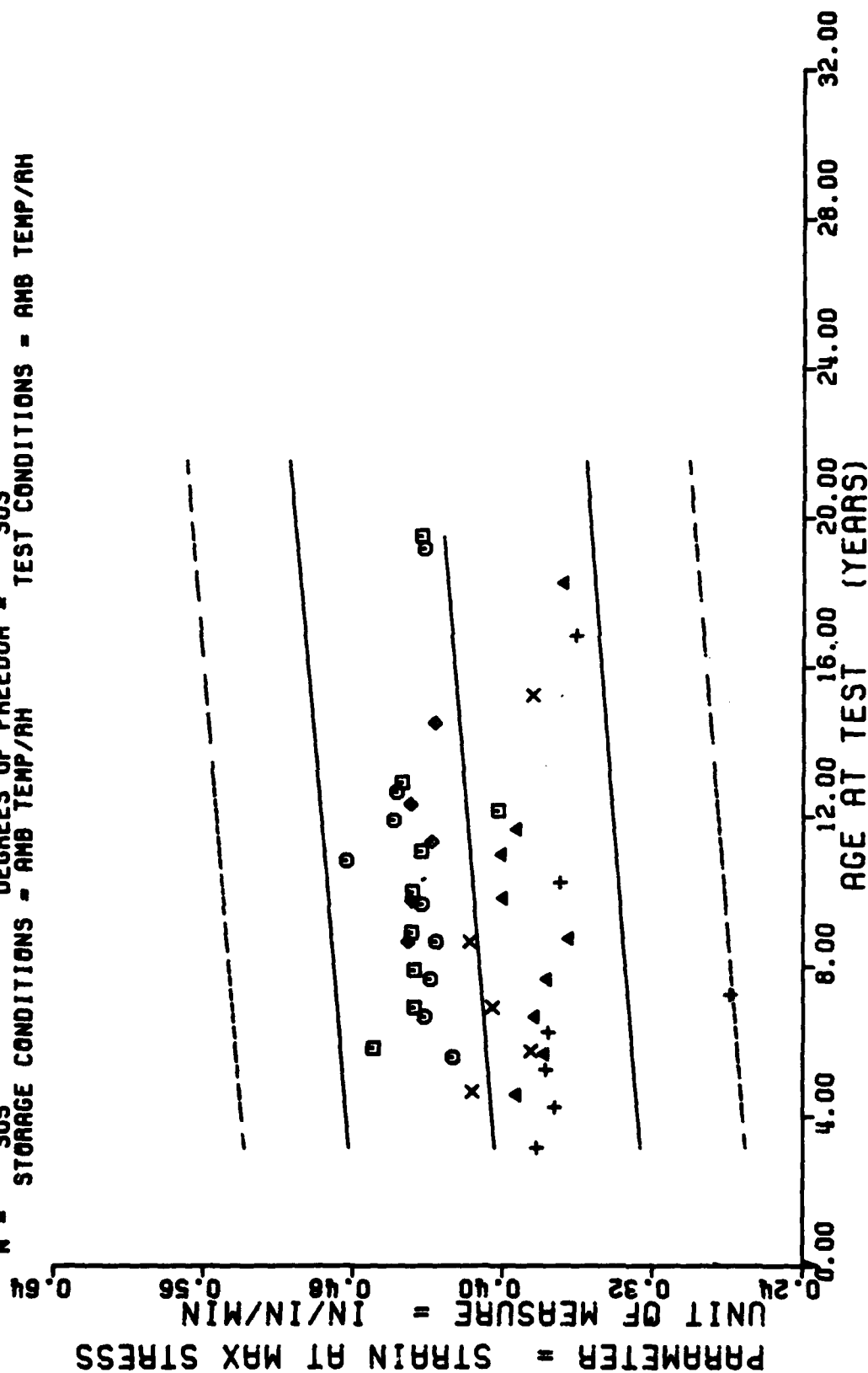
Figure 4-2

$Y = ((+4.7176657E-01) + (+6.3384537E-05) × X)$

F = +1.3069229E+00   SIGNIFICANCE OF F = NOT SIGNIFICANT σ_f = +4.5840116E-02
R = +6.5534361E-02   SIGNIFICANCE OF R = NOT SIGNIFICANT S_o = +5.5444482E-05
t = +1.1432072E+00   SIGNIFICANCE OF t = NOT SIGNIFICANT S_c = +4.5818993E-02
N = 305   DEGREES OF FREEDOM = 303

STORAGE CONDITIONS = AMB TEMP/RH   TEST CONDITIONS = AMB TEMP/RH

PARAMETER = STRAIN AT RUPTURE

UNIT OF MEASURE = IN/IN/MIN

AGE AT TEST (YEARS)
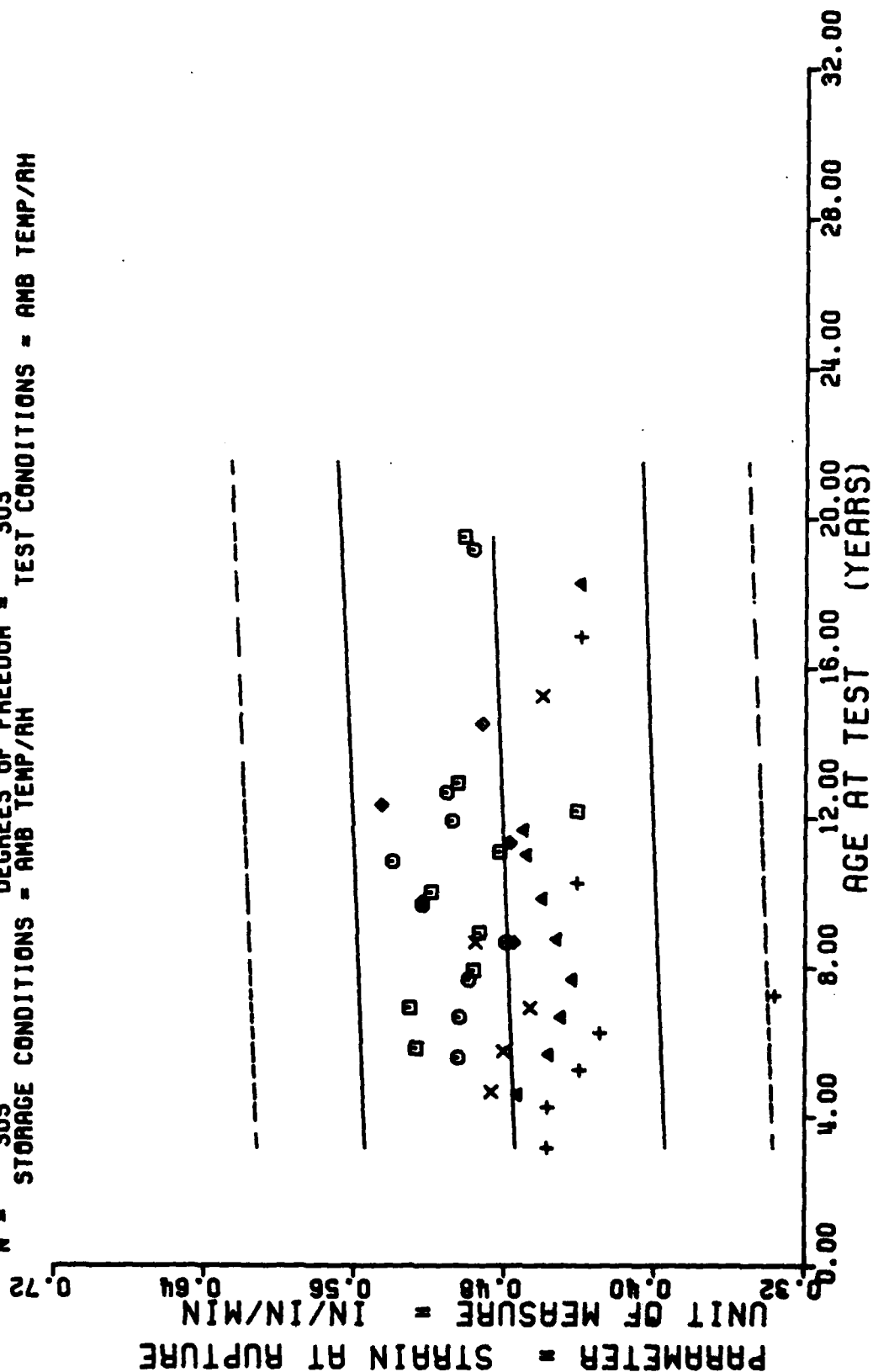
UNIAXIAL TENSILE, STRAIN AT RUPTURE, 2 IN/MIN, SIX MOTOR VISUAL DISPLAY

Figure 4-3

4 - 4

$Y = ((+3.7391614E+02) + (+8.8667381E-02) * X)$

F = +1.0878001E+00	SIGNIFICANCE OF F = NOT SIGNIFICANT	σ_r = +7.0821204E+01
R = +5.9254213E-02	SIGNIFICANCE OF R = NOT SIGNIFICANT	S_1 = +8.5814282E-02
t = +1.0332473E+00	SIGNIFICANCE OF t = NOT SIGNIFICANT	S_2 = +7.0913320E+01
N = 305	DEGREES OF FREEDOM = 303	

STORAGE CONDITIONS = AMB TEMP/RH   TEST CONDITIONS = AMB TEMP/RH
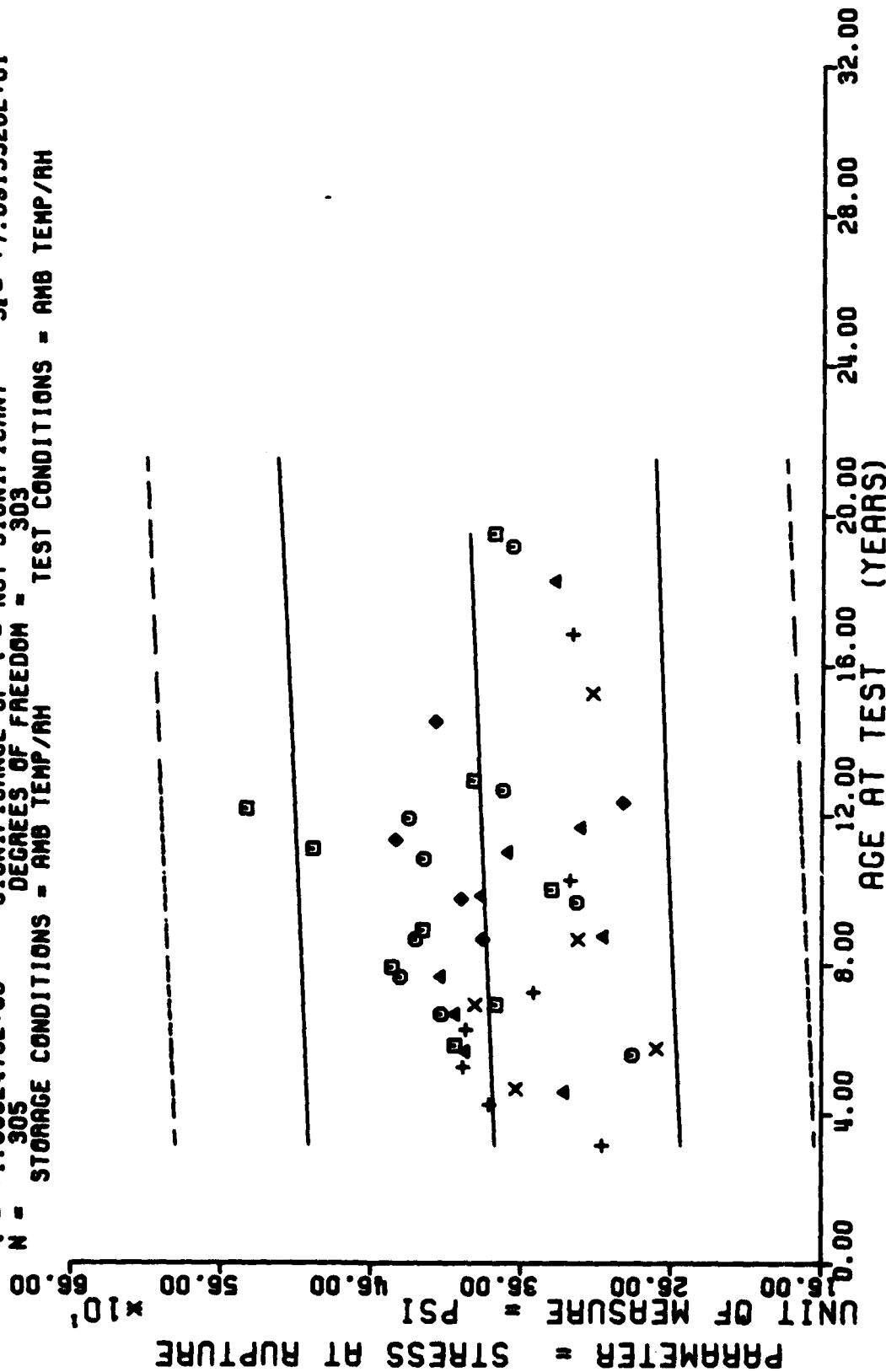
UNIAXIAL TENSILE, RUPTURE STRESS, 2 IN/MIN, SIX MOTOR VISUAL DISPLAY

Figure 4-4

4 - 5

$Y = ((+1.7257823E+03)) + ((+1.3827225E-01) \times X)$

F = +1.9260333E-01   SIGNIFICANCE OF F = NOT SIGNIFICANT σ_r = +2.6001231E+02
R = +2.5204181E-02   SIGNIFICANCE OF R = NOT SIGNIFICANT S_o = +3.1506716E-01
t = +4.3886596E-01   SIGNIFICANCE OF t = NOT SIGNIFICANT S_1 = +2.6035828E+02
N = 305   DEGREES OF FREEDOM = 303
STORAGE CONDITIONS = AMB TEMP/RH   TEST CONDITIONS = AMB TEMP/RH
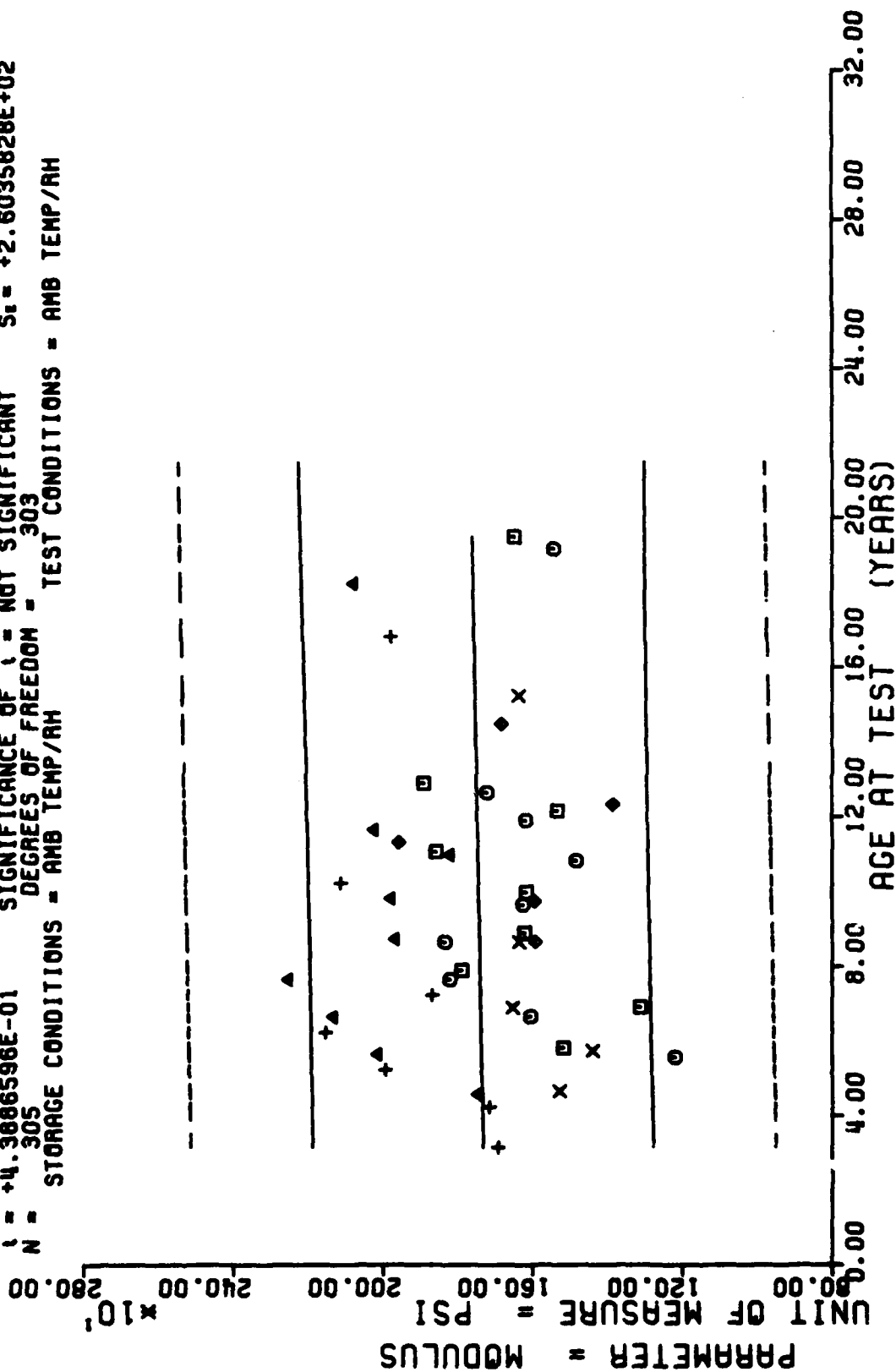
UNIAXIAL TENSILE, MODULUS, 2 IN/MIN, SIX MOTOR VISUAL DISPLAY

AGE AT TEST (YEARS)

UNIT OF MEASURE = PSI

PARAMETER = MODULUS

Figure 4-5

4 - 6

TABLE 4-1

BIAXIAL TENSILE
200 in/min, 300 psi

Motor Nr	N	Parameter	Mean	Std Dev	"t"	Sig of "t"	F	Sig of F
Grain 70	10	Sm, psi	1277.12	32.7988				
	10	em	.3855	.00902	Control Data from Report 412(79)			
	10	er	.3906	.009969				
	10	E, psi	4321.9	252.6079				
			Experimental Data					
0031064	5	Sm, psi	1183.64	14.18	6.0092	Sig	5.3501	NS
	5	em	.3358	.0063	10.9604	Sig	2.0498	NS
	5	er	.3404	.0092	9.4111	Sig	1.1741	NS
	5	E, psi	4824.4	139.93	4.0946	Sig	3.2589	NS
0031134	5	Sm, psi	1157.32	8.33	7.9022	Sig	15.5033	Sig
	5	em	.3542	.0064	6.8830	Sig	1.9863	NS
	5	er	.3596	.0097	5.7245	Sig	1.0561	NS
	5	E, psi	4377.6	91.29	.4703	NS	7.656	Sig
0032434	5	Sm, psi	1164.92	23.83	6.7555	Sig	1.8943	NS
	5	em	.2944	.020	12.4177	Sig	4.9163	Sig
	5	er	.299	.0198	12.1510	Sig	3.9449	Sig
	5	E, psi	6045.4	437.86	9.7966	Sig	3.0045	NS
.0032831	5	Sm, psi	1164.32	17.60	7.1054	Sig	3.4728	NS
	5	em	.2846	.0048	23.1330	Sig	3.5312	NS
	5	er	.292	.0061	20.0954	Sig	2.6707	NS
	5	E, psi	5510.4	133.29	9.7388	Sig	3.5916	NS
0033174	5	Sm, psi	1105.82	20.864	10.5505	Sig	2.4712	NS
	5	em	.3102	.0083	15.6141	Sig	1.1810	NS
	5	er	.3190	.0097	13.2219	Sig	1.0561	NS
	5	E, psi	4778.4	177.56	3.5906	Sig	2.0239	NS

TABLE 4-2

BIAXIAL TENSILE
0.2 in/min, No Pressure

Motor Nr	N	Para-meter	Mean	Std Dev	"t"	Sig of "t"	F	Sig of F
Grain 70	10	Sm, psi	270.98	10.54				
	10	em	.300	.01024	Control Data from Report 412(79)			
	10	er	.3634	.01572				
	10	E, psi	1332	52.84				
		Experimental Data						
0031064	5	Sm, psi	286.74	7.388	2.9724	Sig	2.0352	NS
	5	em	.2776	.00134	4.7818	Sig	58.3969	Sig
	5	er	.3122	.00879	6.6965	Sig	3.7983	NS
	5	E, psi	1486.8	105.43	3.8627	Sig	3.9805	NS
0031134	6	Sm, psi	268.95	2.048	.4603	NS	26.4863	Sig
	6	em	.2708	.00075	6.8769	Sig	186.4135	Sig
	6	er	.3377	.0090	3.6317	Sig	3.0508	NS
	6	E, psi	1490.5	30.37	7.0791	Sig	3.0275	NS
0032434	6	Sm, psi	285.67	1.023	3.3574	Sig	106.1524	Sig
	6	em	.2308	.0012	6.2597	Sig	72.8177	Sig
	6	er	.2892	.0042	11.1805	Sig	14.0089	Sig
		E, psi	1937.3	45.32	23.3098	Sig	3.0275	NS
0032831	5	Sm, psi	278.68	5.93	1.5009	NS	3.1591	NS
	5	em	.2372	.0015	13.3933	Sig	46.6033	Sig
	5	er	.2702	.0066	12.5277	Sig	5.6730	NS
	5	E, psi	1761.6	47.51	13.6979	Sig	1.2371	NS
0033174	6	Sm, psi	256.12	3.93	3.2803	Sig	7.1927	Sig
	6	em	.2425	.0014	13.4921	Sig	53.4987	Sig
	6	er	.3065	.0043	8.5659	Sig	13.3649	Sig
	6	E, psi	1525.5	65.86	6.4795	Sig	1.5533	NS

SECTION V

FRACTURE TOUGHNESS

Critical stress intensity factor as measured from the fracture toughness test shows significantly different means when compared to the means of the Grain 70 data.

All motors have a greater stress intensity factor higher than Grain 70. There is a significant difference in the mean and variance between the three motors with Sunflower grains and the three Radford motors.

TABLE 5-1

FRACTURE TOUGHNESS

Motor Nr	N	Para-meter	Mean	Std Dev	"t"	Sig of "t"	F	Sig of F
Grain 70	10	Time to Rupture	.0822	.0039944	Control Data From Report 412(79)			
	10	K.C.	365.00	22.015				
			Experimental Data					
0031064	6	Time to Rupture	.1078	.0025	14.0278	Sig	2.5528	Sig
	6	K.C.	394.33	6.56	3.1412	Sig	11.2623	Sig
0031134	7	Time to Rupture	.1111	.0040	14.6732	Sig	1.0028	NS
	7	K.C.	406.43	3.78	4.8822	Sig	33.9198	Sig
00.2434	6	Time to Rupture	.0948	.0018	7.2222	NS	4.9244	Sig
	6	K.C.	427.17	3.31	6.7781	Sig	44.2365	Sig
0032831	7	Time to Rupture	.0989	.0040	8.4790	Sig	1.0028	NS
	7	K.C.	415.57	12.25	5.4786	Sig	3.2297	Sig
0033174	6	Time to Rupture	.109	.0034	13.6832	Sig	1.3802	NS
	6	K.C.	422.5	7.92	6.0922	Sig	7.7286	Sig

SECTION VI

AFT BOOT-TO-FLAP
SHORT BOND SHEAR

These specimens were cut from motor 0032619 by Hercules. The area
of interest is the C-7 bond line between the boot and flap rubber. Test
conditions are severe; 30°F, 300 psi and a crosshead speed of 200 in/min.

Data from Hercules for these conditions (MTO 1124-73) show stress
at rupture varying from 249 psi to 730 psi and time to rupture from .041
seconds to .248 seconds for the five motors tested.

All specimens failed at the rubber-rubber interface except one
which failed at a void at the C-7 fill. Most specimens failed during
loading. Those which did not had very low stress, less than 150 psi.
Time to rupture was also short, .041 to .091 seconds.

A different type of fixture will be tried during the next test
period in an attempt to reduce some of the problems associated with the
failures on loading.

SECTION VII

BUNA-S STRESS RELAXATION

Data given by Hercules are for Buna-S obtained from the aft tangent line. Specimens used at OOALC were obtained from case sections. Because this material was thinner than that in the prescribed area, a modified ASTM Die "C" specimen was used in testing.

Problems were encountered, among which was the fact that some specimens had failure strains close to the 2% test level. Variance within each motor is very high and between motors is also high.

SECTION VIII

SUMMARY AND RECOMMENDATIONS

SUMMARY:

There is a significant difference in means and variance between the 1982 testing and the earlier testing of Grain 70. There is a marked difference when compared to prior testing of dissected motors as shown in the biaxial testing. This difference may be the result of aging or may be due to the longer conditioning at $50 \pm 5\%$ RH. A marked decrease in hardness test results have been noted when test specimens are subjected to humidity conditioning.

RECOMMENDATIONS:

1. Testing should be performed on both conditioned and unconditioned specimens to determine the consistency of results.

2. Different specimen holders should be designed for both Buna-S rubber and aft-boot-to-flap specimens. It was determined that the holders presently in use produced poor test results with wide variances.

3. Each motor should be regressed separately to determine the individual aging trends.

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER MANPA Report Nr 480(83)	2. GOVT ACCESSION NO. A128 998	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) MM2 LRSLA Testing, Stage III Propellant		5. TYPE OF REPORT & PERIOD COVERED Test Results - Semi Annual
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) ELIZABETH M. DALABA		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Propellant Analysis Laboratory Directorate of Maintenance OO-ALC Hill AFB, UT 84056		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Airmunitions Management Division Directorate of Materiel Management OO-ALC Hill AFB, UT 84056		12. REPORT DATE April 1983
		13. NUMBER OF PAGES 36
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release, distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Solid Propellant
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Data in this report represents the first LRSLA testing of five dissected motors. Data are compared to Grain 70 propellant which was used in first comparison testing of LRSLA methods and equipment. Problems occurred in testing C-7 bonds which resulted in poor data. Different specimen holders will be designed to alleviate these problems.

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